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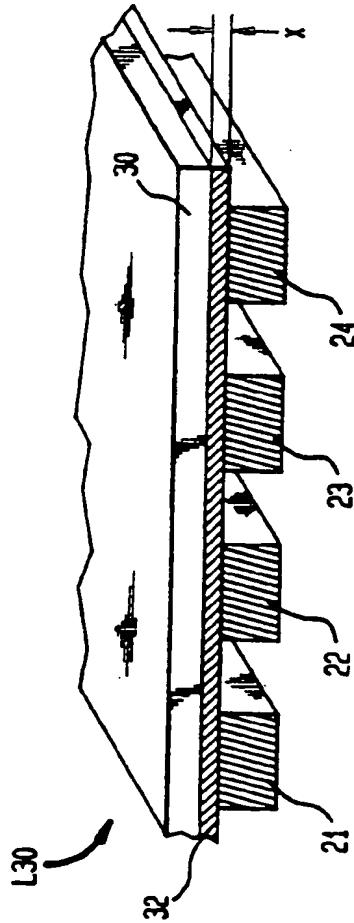
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(54) High Q integrated inductor

(57) An inductive structure is provided which displays an increased self-inductance and improved Q at high frequencies. The improvement resides in the disposition proximate the inductive structure an amount of magnetic material to increase mutual inductance between adjacent portions of the inductor's conductive path with current flow.

FIG. 2B



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Description**Field of the Invention**

The present invention relates to inductors for use in high frequency integrated circuits.

Description of the Related Art

Series resistance is inherent within inductive structures. Series resistance within inductive structures formed by a silicon process dominates the losses occurring during operation as the frequency of operation increases. The losses reduce the inductor's quality factor Q, the ratio of reactance to series resistance within the inductor (when the inductive structure is modeled using a certain topology). Reducing or minimizing the increasing series resistance with increasing frequency, with its concomitant effect on the inductor's Q, is accomplished by increasing the cross-sectional area for current flow within the inductor. Increasing the cross-sectional area may be accomplished by increasing the metalization width or thickness, or both, of the conductive path forming the inductor.

An improved Q displayed by an inductor as a function of increased width W or depth D is substantially linear at DC to the lower frequencies. As the frequency of operation increases, however, current flow through the entire cross-sectional area of the inductor's conductive path, tends to drop off. The current thereafter tends to flow at the outer cross-sectional edges (i.e., perimeters) of the cross-section of the inductor, such as L10 depicted in Fig. 1A. Such current flow is in accordance with the so-called "skin-effect" theory.

Inductors formed for use within integrated circuits are typically spiral-shaped. Fig. 1B shows a portion of a conventional spiral inductor, L20, formed with an aluminum conductor 24 on a silicon substrate 22. Fig. 1C shows a cross-sectional portion of the conductive path of conductor 24. W and L represent the conductor's width and length, respectively, and D represents its depth. L is the summation of individual lengths l_1, l_2, \dots, l_N comprising the inductor's conductive path. Because the conductive path is spiral-shaped (although not clear from the cross-sectional view in the figure), magnetic fields induced by current flow tend to force the current to flow along the inner or shorter edges of the spiral conductive path (shown hatched). Because of these "edge effects", increasing the width W beyond a particular point (and therefore the cross-sectional area), as mentioned above, ceases to show a concomitant improvement in the inductor's Q with increasing frequency. The thickness or depth D of the conductive path must be increased, or the magnetic coupling between adjacent turns must be increased, to provide the required Q.

Summary of The Invention

The present invention provides an inductor fabricated for semiconductor use which displays an increased self-inductance and improved Q not realizable with conventional integrated inductor fabrication techniques. Consequently, inductors formed in accordance with this invention may be utilized within a frequency range of around 100 MHz to substantially beyond 10 GHz. During operation, inductive structures of this invention display Q's in a range of around 2 to around 15.

For an inductive structure formed as a spiral with a particular number of turns N, the addition of the core of magnetic material described herein results in a higher inductance for the structure. To put it another way, a reduced number of turns may be used within an inductive structure of this invention, relative an inductive structure of the prior art, and derive a similar inductance value. Because fewer turns are used within a structure formed in accordance with the present invention, the parasitic capacitance in the structure will be lower.

In one form, the mutual inductance between adjacent metal runners forming the conductive path of an inductive structure is increased. Additionally, the series resistance displayed by the conductive path remains fixed, i.e., does not degrade substantially with increasing frequency. This provides for stable or improved Q values with varying frequency. The structural arrangement includes the deposition of a portion, preferably a plane, of high permeability magnetic material above the metal runners forming the inductor's conductive path.

The layer of magnetic material is further arranged to provide a low reluctance path and to maximize magnetic coupling between path elements while providing a high resistance path to eddy currents induced in the core. The arrangement maximizes the inductance of the structure while minimizing eddy current losses induced in the core which degrade the inductor's Q. Preferably, the high permeability magnetic material does not have any electrical connections to the integrated circuitry of which the inductive structure is a part. The process of providing the layer of high permeability magnetic material is believed compatible with the existing silicon manufacturing processes.

Brief Description of The Drawings

Figure 1A is a cross-section of a rectangular conductor of the prior art;

Figure 1B is plan view of a portion of a spiral inductor formed with conventional silicon fabrication techniques;

Figure 1C is cross-sectional view of a portion of conductive path forming a spiral inductor via conventional fabrication techniques;

Figure 2A is a plan view of a spiral integrated inductive structure of this invention;

Figure 2B is a cross-sectional view of a portion of

the spiral conductor of Figure 2A; and Figures 3A, 3B and 3C are plan views of various forms of planes of high permeability magnetic material included within the present invention.

Detailed Description of The Preferred Embodiments

The inductive structure of this invention is provided for use within high frequency semiconductor integrated circuits. The inductive structure displays an improved inductance for a fixed value of series resistance inherent within the conductive path forming the inductor. The improved inductance leads to a realization of quality factor (Q) for the invention between values of 10 to 16 at very high frequencies, unrealizable within the prior art. The range of operation of inductors formed as described herein extends from around 100 MHz to around 10 GHz.

Figs. 2A and 2B show spiral and cross-sectional portions, respectively, of several conductive elements 21, 22, 23, 24, 25 forming a spiral conductive path of an inductive structure L30 of this invention. The conductive paths may be disposed on or within a substrate material such as a semiconductive material, a substrate material or a dielectric material. An example of a non-conductive substrate is gallium arsenide (GaAs), usually described as semi-insulating.

A portion of high magnetic permeability material 30 is disposed at a distance X from the conductive path elements and separated therefrom by a layer of dielectric material 32. The high permeability magnetic material is preferably planar-shaped and provides a low reluctance path which raises the mutual inductance induced between adjacent runners with current flow. As is clear from the figures, the high magnetic permeability material is not electrically connected to any portion of the circuitry contained within the integrated circuit.

Use of the plane of high magnetic permeability material 30 (plane or core), as described above, is beneficial but does introduce a complication within the semiconductor circuit. Eddy currents are generated within the magnetic material which deplete energy as heat loss. Eddy currents are induced when a changing flux passes through a solid magnetic mass, such as iron, from which the layer 30 may be comprised.

Referring now to Figure 2C, alternating current, flowing into the plane of the paper on the right side of Figure 2C (lands 22-24), and out of the plane of the paper on the left (lands 25-27), generate a changing magnetic flux affecting core 30. The flux fields are identified by the circular arrows, identifying flux direction. The flux induces a current in the magnetic material (core 30) commensurate with the induced flux.

When changing magnetic flux densities are high, eddy currents are responsible for significant power loss. Eddy current loss is related to the square of the frequency and the square of the maximum flux density.

To minimize eddy currents in iron-core transformers (and the loss associated therewith), the core is formed

of blocks or sheets of laminate disposed parallel to the flux direction. As shown in Figs. 3A, 3B and 3C, a changing applied flux (directed into or out of the plane of the paper, relative the central hole) induces a net current

5 within the planes of core material 30. The induced current flow is indicated with the circular arrows. Consequently, the induced eddy current produces a time-changing flux (directed out of the plane of the paper) in opposition to the changing applied flux, thereby reducing 10 the total time changing applied flux through the core. Eddy currents are induced perpendicular to the direction of the changing flux. Accordingly, the induced eddy currents may be minimized by breaking up the core into thin sections or sheets. Accordingly, the circulating eddy currents 15 paths are limited, resulting in reduced eddy current losses within the total mass of magnetic material.

The shape of the planar core 30 shown in Figure 3A includes a rectangular hole substantially at its center.

The rectangular hole reduces undesired magnetic coupling 20 between runners on opposite sides of the inductor relative the center. The design, however, does not address problems associated with the generation of eddy currents. Fig. 3B, shows the core (i.e., the planar cor 25 of the preferred embodiment) broken up into wedges and including the hole in the center for the reasons discussed above. This design reduces both unwanted coupling and eddy current loss with respect to the design of Fig. 3A. Fig. 3C shows the use of multiple strips of magnetic material to form the planar core. Such design further reduces eddy current loss relative to the design of 30 Figure 3B. The strips of magnetic material are preferably at right angles (orthogonal) to the lines formed by the metal runners forming the inductor's conductive.

What has been described herein is merely illustrative of the application of the principles of the present invention. Other arrangements and methods may implemented by those skilled in the art without departing from the scope of this invention.

Claims

1. An inductive structure formed on or within a substrate and integrable with a semiconductor integrated circuit, comprising:
- a) an electrical conductor (21-28) providing a conductive path formed as a spiral planar pattern upon or within said substrate, wherein adjacent lengths of said path are substantially parallel. **CHARACTERISED BY:**
- b) a core (30) of magnetic material disposed above said planar pattern such that a mutual inductance induced within said adjacent lengths by current flow is increased by said core, and an amount of eddy current loss generated within said core is controlled.

2. The inductive structure defined by claim 1, wherein said core is formed of a high permeability magnetic material.
3. The inductive structure defined by claim 1 or claim 2, wherein said core is arranged with a centralized discontinuity to reduce the inducement of non-desirable inductances within lengths of said spiral planar pattern.
10
4. The inductive structure defined by claim 1 or claim 2, wherein said core includes four electrically isolated wedge-designed portions, said four portions arranged with a central discontinuity to reduce inducement of non-desirable inductance within lengths of said conductive path disposed on opposite sides of said spiral pattern, and to reduce eddy current losses within said core.
15
5. The inductive structure defined by claim 4, wherein said wedge-designed portions are formed of multiple strips of magnetic material to further reduce eddy current losses within said structure.
20
6. The inductive structure defined by claim 5, wherein multiple strips are disposed substantially at right angles to substantially adjacent lengths of said conductive path.
25
7. The inductive structure defined by any of the preceding claims wherein said core is planar.
30
8. The inductive structure defined by any of the preceding claims further including a mass of dielectric material disposed upon said pattern to electrically isolate said pattern from said core.
35
9. The inductive structure defined by any of the preceding claims wherein said substrate is formed of one of: a semi-conductive, a non-conductive and a dielectric material.
40
10. The inductive structure defined by any of the preceding claims wherein said pattern and said core are positioned to provide high frequency operation to around 12 GHz.
45
11. A semiconductor integrated circuit including an inductive structure as defined by any of the preceding claims.
50

FIG. 1A

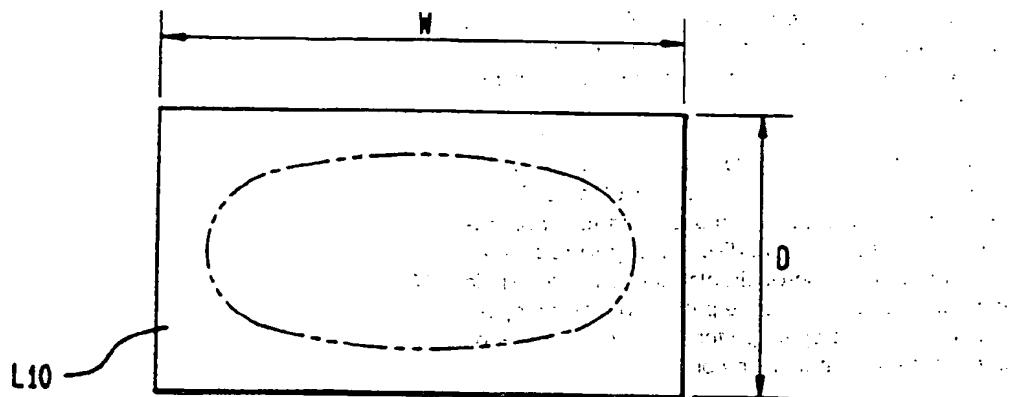
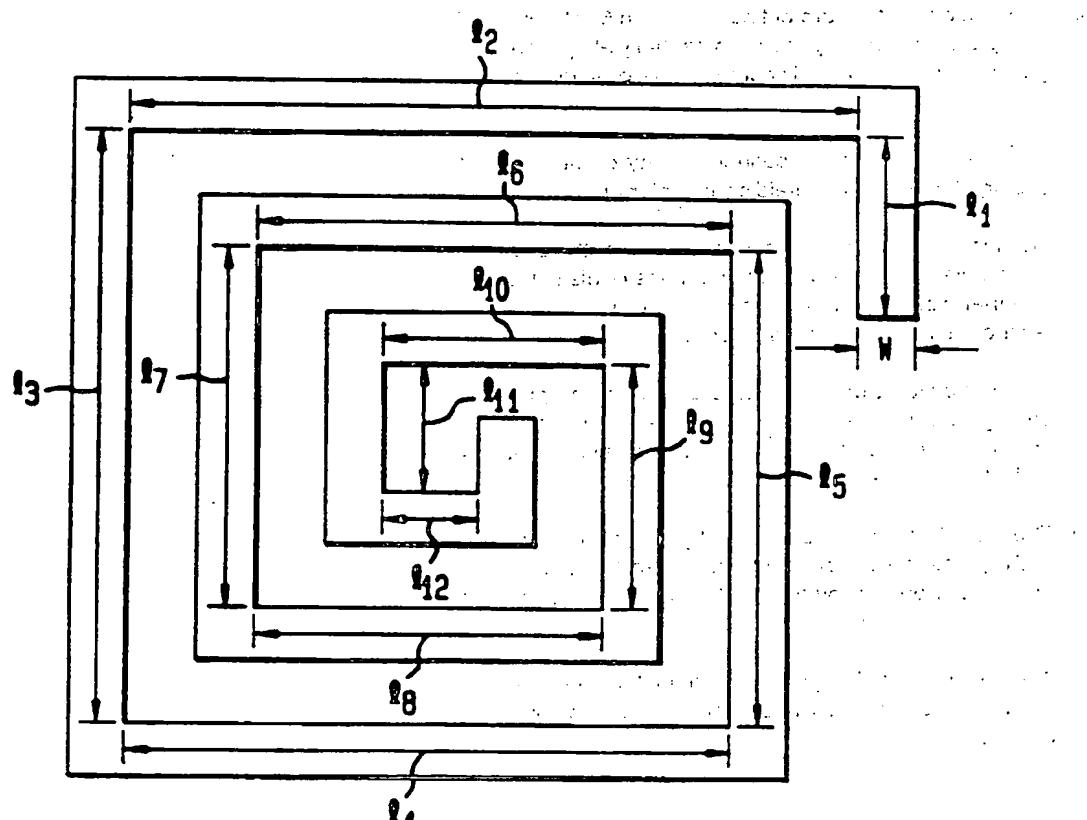


FIG. 1B



$$L = \sum_{n=1}^{12} L_j$$

FIG. 1C

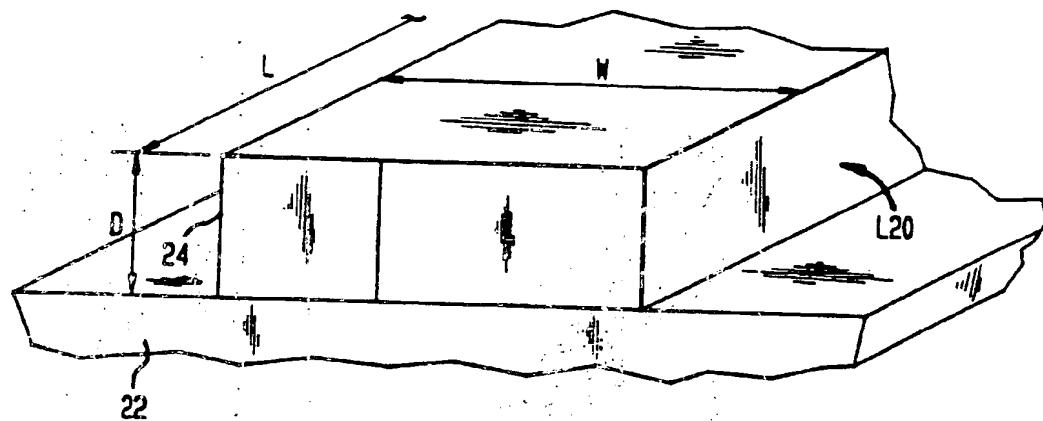


FIG. 2A

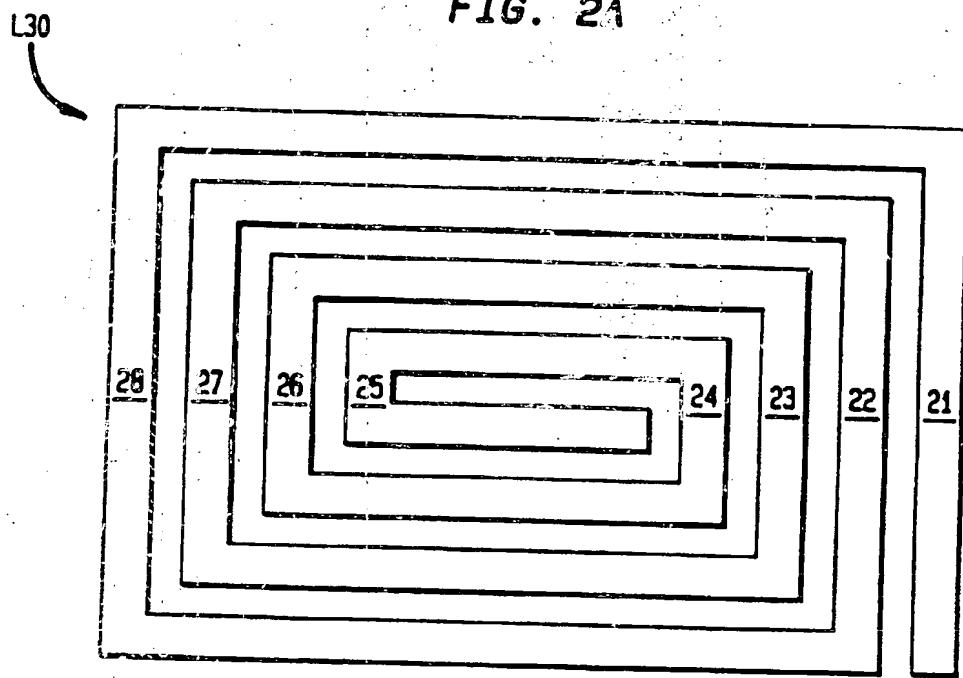


FIG. 2B

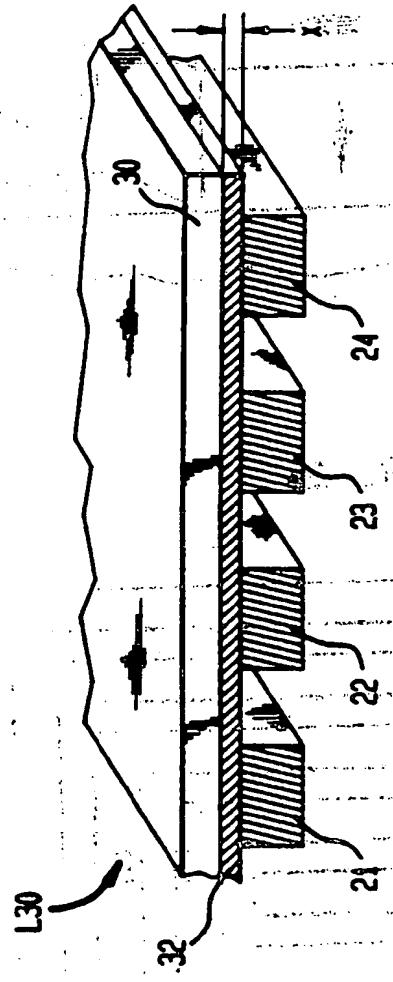


FIG. 2C

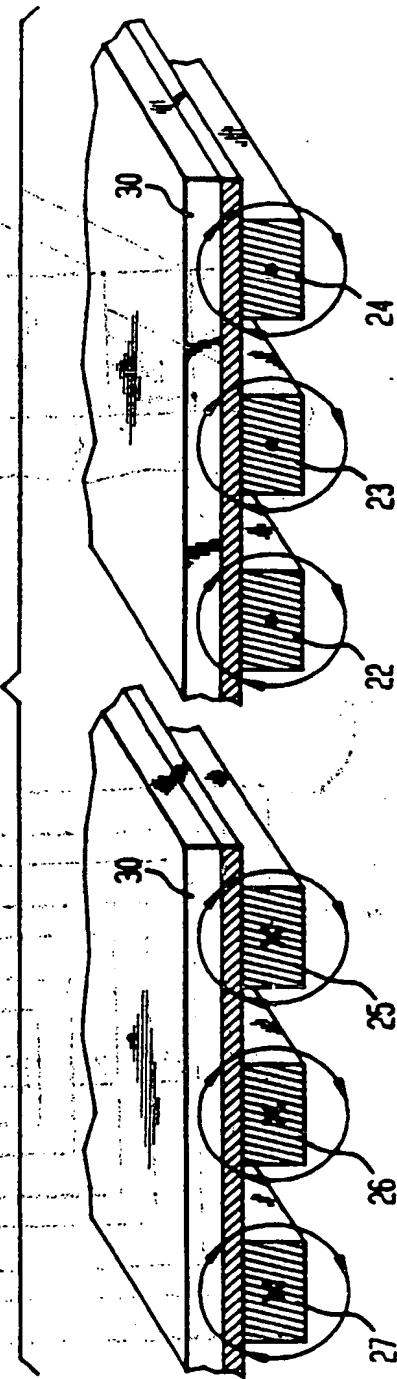


FIG. 3A

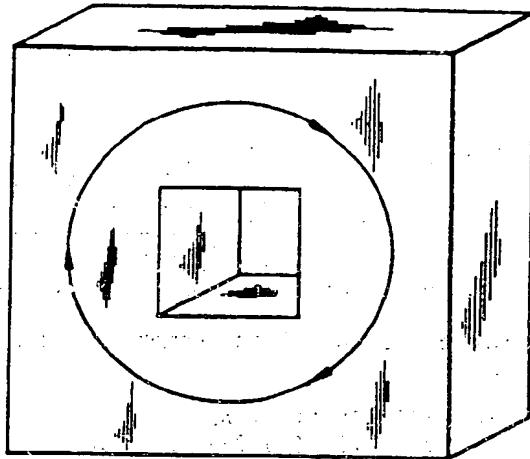


FIG. 3B

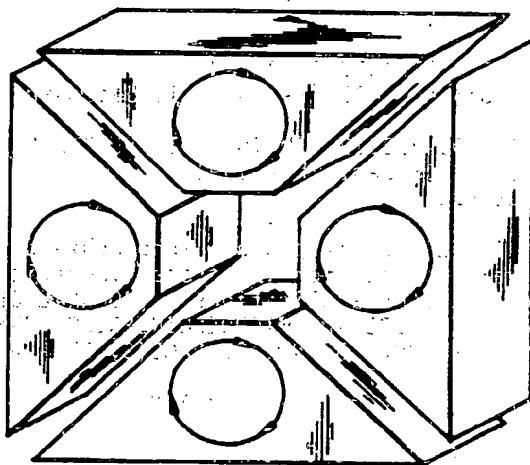
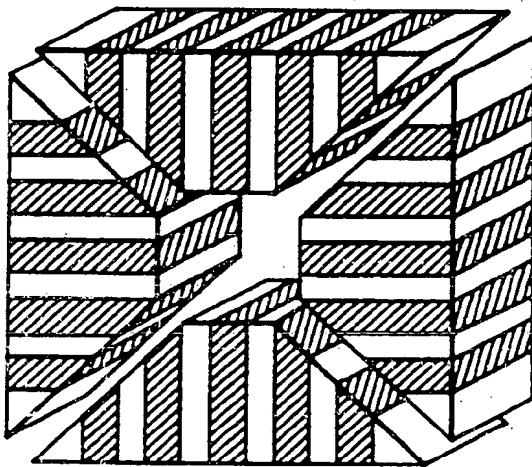


FIG. 3C





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EUROPEAN SEARCH REPORT

Application Number
EP 95 30 8539

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int.Cl.)						
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim							
A	IBM TECHNICAL DISCLOSURE BULLETIN, vol. 8, no. 5, October 1965 NEW YORK, US, page 723. ANONYMOUS 'Etched Transformer. October 1965.'	1,7-9	H01F17/00 H01F27/34						
A	PATENT ABSTRACTS OF JAPAN vol. 016 no. 079 (E-1171) ,26 February 1992 & JP-A-03 268410 (AMORFUASU DENSHI DEVICE KENKYUSHO:KK) 29 November 1991, * abstract *	1,3,4,7,8							
A	PATENT ABSTRACTS OF JAPAN vol. 015 no. 490 (E-1144) ,11 December 1991 & JP-A-03 212913 (MATSUSHITA ELECTRIC IND CO LTD) 18 September 1991, * abstract *	1							
A	AHN C H ET AL 'A planar micromachined spiral inductor for integrated magnetic microactuator applications' JOURNAL OF MICROMECHANICS AND MICROENGINEERING, JUNE 1993, UK, VOL. 3, NR. 2, PAGE(S) 37 - 44 , ISSN 0960-1317 * page 1 - page 2; figure 1 *	1,2,4	TECHNICAL FIELDS SEARCHED (Int.Cl.)						
A	PATENT ABSTRACTS OF JAPAN vol. 016 no. 263 (E-1216) ,15 June 1992 & JP-A-04 061210 (NIPPON TELEGR & TELEPH CORP) 27 February 1992, * abstract *	1,9	H01F						
<p>The present search report has been drawn up for all claims.</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 33%;">Place of search</td> <td style="width: 33%;">Date of completion of the search</td> <td style="width: 34%;">Examiner</td> </tr> <tr> <td>THE HAGUE</td> <td>7 March 1996</td> <td>Marti Almeda, R</td> </tr> </table> <p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>I : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p>				Place of search	Date of completion of the search	Examiner	THE HAGUE	7 March 1996	Marti Almeda, R
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THE HAGUE	7 March 1996	Marti Almeda, R							



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EUROPEAN SEARCH REPORT

Application Number
EP 95 30 8539

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
A	PATENT ABSTRACTS OF JAPAN vol. 012 no. 228 (E-627) ,28 June 1988 & JP-A-63 020810 (HITACHI LTD) 28 January 1988, * abstract *		
A	PATENT ABSTRACTS OF JAPAN vol. 007 no. 166 (E-188) ,21 July 1958 & JP-A-58 073105 (NIPPON DENKI KK) 2 May 1983, * abstract *		
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
<p>The present search report has been drawn up for all claims</p>			
Place of search	Date of completion of the search	Examiner	
THE HAGUE	7 March 1996	Marti Almeda, R	
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